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A DUAL TELESCOPE FOR SPECTROHELIOGRAPHY IN THE EXTREME ULTRA-VIOLET

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GREENBELT, MARYLAND

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1. INTRODUCTION

A high resolution x-ray telescope experiment was proposed and scheduled for flight on AOSO.(1) As stated in the original proposal "The measurements of intensity, spatial and temporal resolution will be compared with ground based visible and radio observations with the objective of better understanding the dynamics (temperature, density, ion composition, etc.) of the solar atmosphere." The x-ray telescope was to have a resolution of 5 arc seconds, use filters to cover the wavelength region from 3 to 60 A, and obtain solar images every 5 minutes.

The objectives of the experiment proposed for ATM are the same. The same type telescopes, filters, resolutions and general spectral range are proposed. The added capability of ATM will be used to obtain more detailed time histories. To meet the severe schedule constraints, two telescopes with fixed filters will be used instead of a single telescope with a changeable filter.

2. OBJECTIVES

By using the capabilities of the ATM pointing control planned for the Apollo Applications Program, we propose to trace the development

(1) Lindsay, J. C. and Giacconi, R., "High Resolution (5 arc sec) X-ray Telescope for Advanced Orbiting Solar Observatory", GSFC Report X-614-63-112

in time and space of typical solar centers of activity by observing selected coronal radiations from Fe XVII in the 15-17 A region and by observations of lower excitation phenomena in the 44-60 A region.

Imaging will be done simultaneously in these two band passes; the general structure of the lower corona will be mapped in the 44-60 A region and the development of centers of high activity will be traced in Fe XVII; both images will have a resolution of 5 seconds of arc on axis and will be obtained photographically from two X-ray/EUV telescopes. Concurrent with the imaging, both of these radiations will be observed in integrated fashion over the entire solar hemisphere.

From this data it should be possible to trace the development of various active regions in the solar atmosphere during the 14 day ATM mission. While 14 days is not enough time to trace the complete life history of a center of activity, it can be expected that enough centers will be observable on the sun at the time of the flight to allow us to measure the coronal conditions for centers at various stages of development. In addition this experiment will have the capability of obtaining pictorial histories of the development of representative highly transient solar phenomena, e.g. flares, in the x-ray region for correlation with ground based data.

3. SCIENTIFIC BACKGROUND

A considerable amount of information regarding the physical state of the solar corona can be obtained from observations in the extreme

ultraviolet and X-ray regions (350 A to 1 A). By measuring the intensities of spectral lines of highly ionized atoms and the distribution of brightness in these lines across the solar disc, one may determine for example, the electron density and temperature of specific structures in the corona. This information can contribute to the eventual solution of the problems of the mechanisms for energy and mass transport into the corona, and the relationships of these mechanisms to observed photospheric and chromospheric structures. For this, one requires precise observations of the lower regions of the corona. Such observations have been made (but only at the limb) using coronagraphs, and for a few moments during total eclipses using spectrograph-camera combinations. As the photospheric continuum radiation is so intense in the visible wavelength region, it has not been possible to make observations of the corona in front of the solar disc at visible wavelenghts. Even in limb observations, scattered photospheric radiation can be a serious problem. At EUV and X-ray wavelengths, however, this problem does not occur.

By observing the sun in these short wavelengths, one may also hope to obtain a better understanding of solar flares. For this one requires an instrument of sufficient spatial resolution to enable the X-ray flare to be closely compared with the Hα flare and the underlying sunspots and plages.

A major advance in short wavelength studies of the sun was made on March 17, 1965, with the first successful use of grazing-incidence

X-ray optics to obtain X-ray pictures of the corona. This experiment, flown on an Aerobee rocket from White Sands, was conducted jointly by the Solar Physics Branch of Goddard Space Flight Center and the American Science and Engineering, Inc., of Cambridge, Massachusetts. A number of X-ray pictures were obtained through various filters which served to define the wavelength region observed; the experiment convincingly demonstrated the potential of this new technique. Although these first pictures achieved a resolution of only one or two minutes of arc, improved techniques of mirror fabrication under investigation by the Solar Physics Branch at GSFC are now enabling resolutions of the order of a few seconds of arc to be obtained.

4. DESIGN OF INSTRUMENTS

4.1 Imaging Elements

We propose to use two telescopes, each of which will be capable of resolving solar details down to a size of 5 arc seconds. The proposed imaging mirrors will each have an internal diameter of approximately 7" and a length of 12" and will be separated by 10", center-to-center.

Considerations of film grain (discussed later) dictate that the solar image should be at least 16mm in diameter, if we are to achieve 5 arc-seconds resolution. For each of the two telescopes we propose to use an imaging element having an effective focal length

of 75 inches, giving a solar image of 17.7mm diameter. The proposed element will be a grazing-incidence paraboloid combination of the first kind[2] with a collecting area of 38.5 cm^2. As the aperture is annular, the focal ratio as defined in the usual manner has no meaning for exposure purposes; but we may define an "equivalent f-number" as being the ratio of the diameter of the equivalent circular area to the focal length of the telescope. Defined in this way, the proposed element operates at f/27. This compares very favorably with the f/1000 of a typical pinhole camera or the f/300 of a typical zone plate telescope.

During the past several years the Solar Physics Branch in conjunction with various contractors and research group has been investigating techniques of fabricating grazing-incidence X-ray telescopes. In the past most of the telescopes have been fabricated by electro forming. The early results from this technique were quite encouraging, however, during the past year it has become obvious that further improvement of the optical performance by electro forming is going to be very difficult if not impossible. It has not been possible to obtain the final surface finishes which are required with the result that too much light has been scattered over the whole field.

[2] Wolter, H., Ann. der Phys. 10, 94 (1952)

Approximately one year ago a program was initiated to attempt to fabricate X-ray optics using classical optical techniques. The results to date have been very encouraging. An example of a small X-ray telescope fabricated in stainless steel for GSFC by the Speedring Corporation is shown in Figure 1. This telecope operates at f/44. Figure 2 is a visible photograph taken with this telescope. The resolution indicated by this picture is approximately 7 seconds of arc over a field of view of 45 minutes of arc. Even though the final surface finish is still not up to the optical quality normally required for astronomical purposes its performance is better than that achieved by the earlier techniques. It should be noted, however, that this telescope is still only a first approximation to what is possible, since the two optical surfaces are cones instead of being the paraboloid-hyperboloid combination we propose to use. Perkin Elmer is presently in the final stage of assembly of a similar telescope in Quartz but with paraboloid-hyperboloid surfaces of high optical quality. Preliminary tests are indicating surfaces to at least $1/30\lambda$ in the visible. They have encountered no unforseen fabrication problems. We therefore propose to use this technique for the ATM mirror fabrication.

Each telescope will be fabricated by grinding and polishing from quartz. Multiple-beam interferometric techniques will be used

to monitor the final polishing process, in order to achieve a surface figure accurate to at least 1/30 wavelength of visible light. The first surface will operate at a grazing angle of incidence of approximately 1° 30' and the second surface at about 1° 7' for the short λ telescope.

The combined reflection efficiency for telescopes operating at these angles is given in Table I. On the basis of the past experience in obtaining X-ray images of the sun we estimate that the time resolution for this system to be of the order of 10 sec. or less.

TABLE I

λ(A)	REFLECTION EFFICIENCY	
	Glass	Stainless Steel
13.3	35%	42%
16.	17%	35%
31.4	56%	69%
44	75%	75%

4.2 Film and Camera

The most useful emulsions for work in the EUV and X-ray region are those with a high silver content and little or no protective

supercoat of gelatin, such as Ilford Special Unsupercoated Industrial G, Kodak-Pathe SC7 and SWR. These are the fastest emulsions now available for this wavelength region; but they are also quite grainy, having a resolving power of perhaps 24 lines/mm. A fairly large solar image is therefore required (16mm diameter at 5 arc-seconds resolution). These films are also extremely sensitive to pressure and abrasion, and it is not feasible to roll them tightly on a reel without some means of spacing the turns away from each other. We propose to use a film strip 70mm wide with double-thickness edges extending inward 23mm on each side, leaving a central strip 24mm wide within which the 17.7mm solar images will be centered.

It is estimated that the camera proper would extend no more than 15 inches behind the focal plane; the total length of the experiment would therefore be about 90 inches.

4.3 Filters

Each telescope will contain a single fixed filter; one will use quarter-mil aluminum (8-17 A passband) and the other mylar coated with aluminum. Most of the energy in the Al passband is contributed by lines of Fe XVII lying between 13 and 17 A; similarly, the major components in the mylar passband are lines of Si IX and Si X .

4.4 Ancillary Sensors

We plan to use 3 proportional counters in addition to the two X-ray telescopes. Two of the counters will work in approximately

the same wavelength regions as the telescopes. One in the 8-20 Angstrom region the other in the 44-60 Angstrom region. These will be used to put an absolute calibration on the X-ray pictures. The third sensor will operate in the 2-8 Angstrom region. Its primary purpose will be to monitor highly transient activity. Each of the sensors will employ electronic pulse-counting with subsequent registry of their integrated outputs as binary numbers on a bank of neon bulbs. At regular intervals, the binary numbers will be transferred as a string of light and dark spots onto an appropriate data frame on the photographic film.

Note that the data from any of the three ancillary sensors is initially in a pulse-rate form. This data will also be recorded on the on-board tape recorder. It will thus be an easy electronic task to provide the astronaut with a suitable simple display from these sensors; we propose to do this, and also to provide him with an indicator of the mode the experiment is in at any moment ("Quiet" or "Active"). The purpose of this display is explained in the next section of this proposal.

5. OBSERVING SCHEDULE

Our proposed observing schedule is tailored to the following set of ground rules.

(a) 14-day mission.

(b) 90 hours of actual observing time.

(c) 1000 feet of film, preferably 70mm wide.

(d) Astronaut will have an "X-ray activity meter" supplied by this experiment; he will be able to override the internal experiment logic in exceptional or unforeseen situations. The actual amount of in orbit logic changing is dependent upon the number of command lines available to the experimenter.

We plan to use a format on the film such that data are presented in sets of three items each; viz., (1) a solar image in 44-60 A, (2) a solar image in Fe XVII, and (3) a frame of binarized data from the ancillary sensors, including a portion of the film devoted to calibration and/or a fog reference level. Each set will occupy a maximum of 3 inches along the film; the separate parts of each data set will be positioned in a fixed relation to each other, probably not contiguous (See Figure 3) owing to the planned simultaneous exposure of the film through three gates spaced 5 inches apart. A film capacity of 1000 feet will allow 4000 data sets to be taken.

5.1 Exposure Program

In order to sensibly apportion the film footage and at the same time obtain useful statistics, we plan for approximately 89% of the 90 observing hours to operate in a low data-rate "quiet" mode wherein one data set is taken every 12 minutes; 100 feet of film is

allocated to this mode, corresponding to 400 data sets or 4800 minutes of observing time. The remaining 11% of the observing time will be devoted to a high data-rate "active" mode wherein one data set is taken every 10 seconds; 900 feet of film will be used for 3600 data sets or 600 minutes of observing time. As an example of how this 600 minutes of "active" mode time might be used, one might, for instance, register two 100-minute large events and twenty 20-minute moderate-to-small events. Table II summarizes the exposure program.

A system of thresholding logic will be used to define when the experiment should switch from "quiet" to "active" mode, there to remain for a pre-set interval of 20 minutes unless over-ridden by the astronaut who may, at his option, hold the "active" mode for a much longer period.

TABLE II

Mode	Period Between Exposures	Data Sets	Total Time	Film Footage
Quiet	12 min.	400	80 hr.	100
Active	10 sec.	3600	10 hr.	900
TOTAL		4000	90 hr.	1000

6. WEIGHT AND POWER

Power for the actual operation of the experiment will be less than 10 Watts average. However, it should be realized that it may be necessary to supply active heating elements to the experiments to solve the thermal problems. The weight of the experiment is difficult to estimate at the present time because of the unknown interfaces with the ATM and the unknown requirements which will be placed on us by the astronauts for EVA recovery of the film. However, the experiment should weight approximately 150 pounds if no radiation shielding is required, and if no unusual requirements are received from the ATM contractor or the astronauts.

7. PROBLEM AREAS

As pointed out above, timely solution of the interfaces between the various experimenters and the ATM mount is imperative. Contamination from the life support system for the astronauts, and from the jets in the Apollo guidance and control system poses serious problems for any optical experiment. If the Co^{60} sources are left in the service module, and if the experiment is unshielded, the film will become unusable in a fraction of an hour. The shielding required to protect the film from this radiation environment (if it must be supplied by the experiment) might possibly weigh more than the original experiment.

8. DELIVERY SCHEDULE

The present schedule for experiments requires that the experiments must be delivered to GSFC in July 1967 for testing and integration in order to meet the first launch date. The relatively simple experiment proposed can meet this schedule if timely definitions of the interfaces are made.

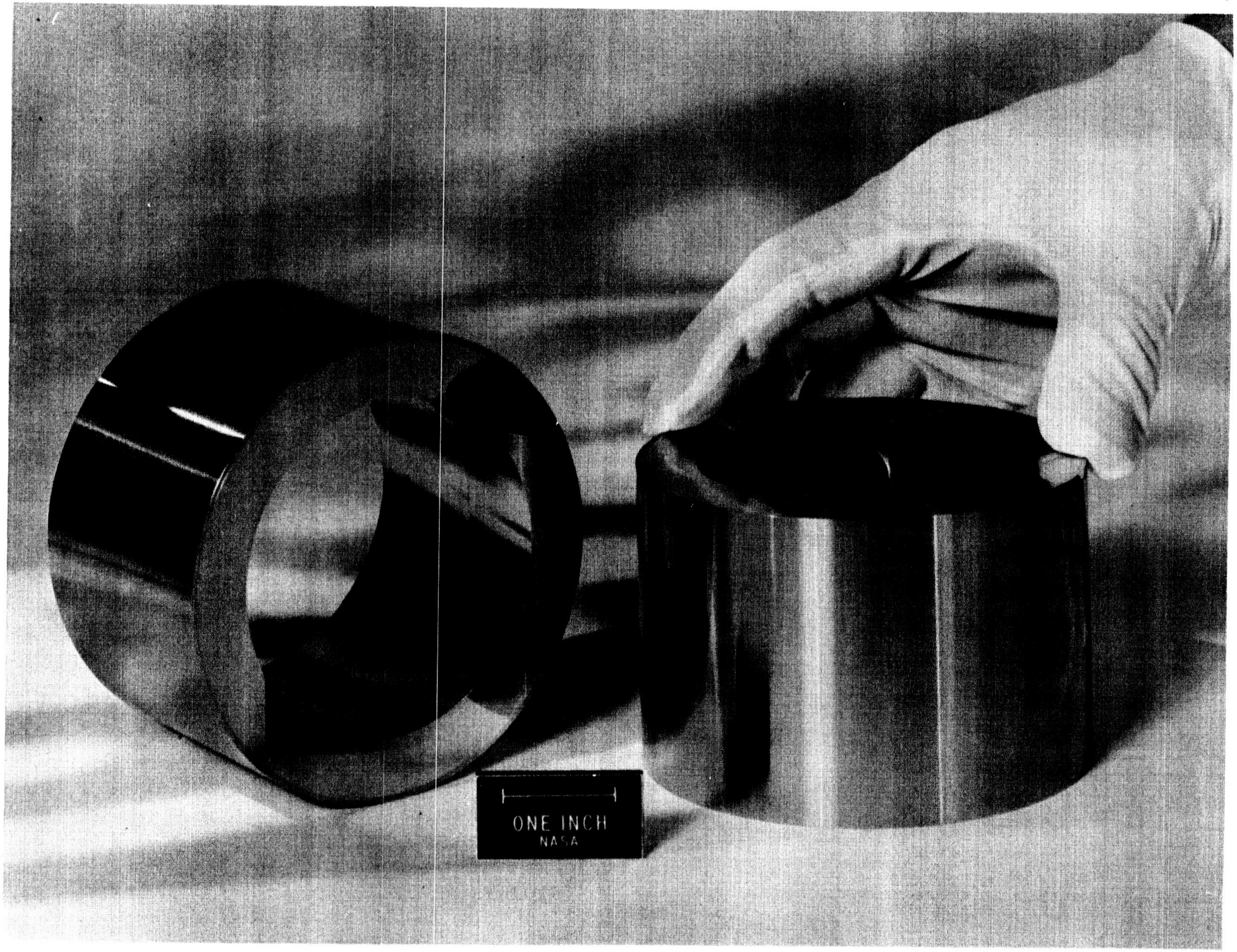

Figure 1

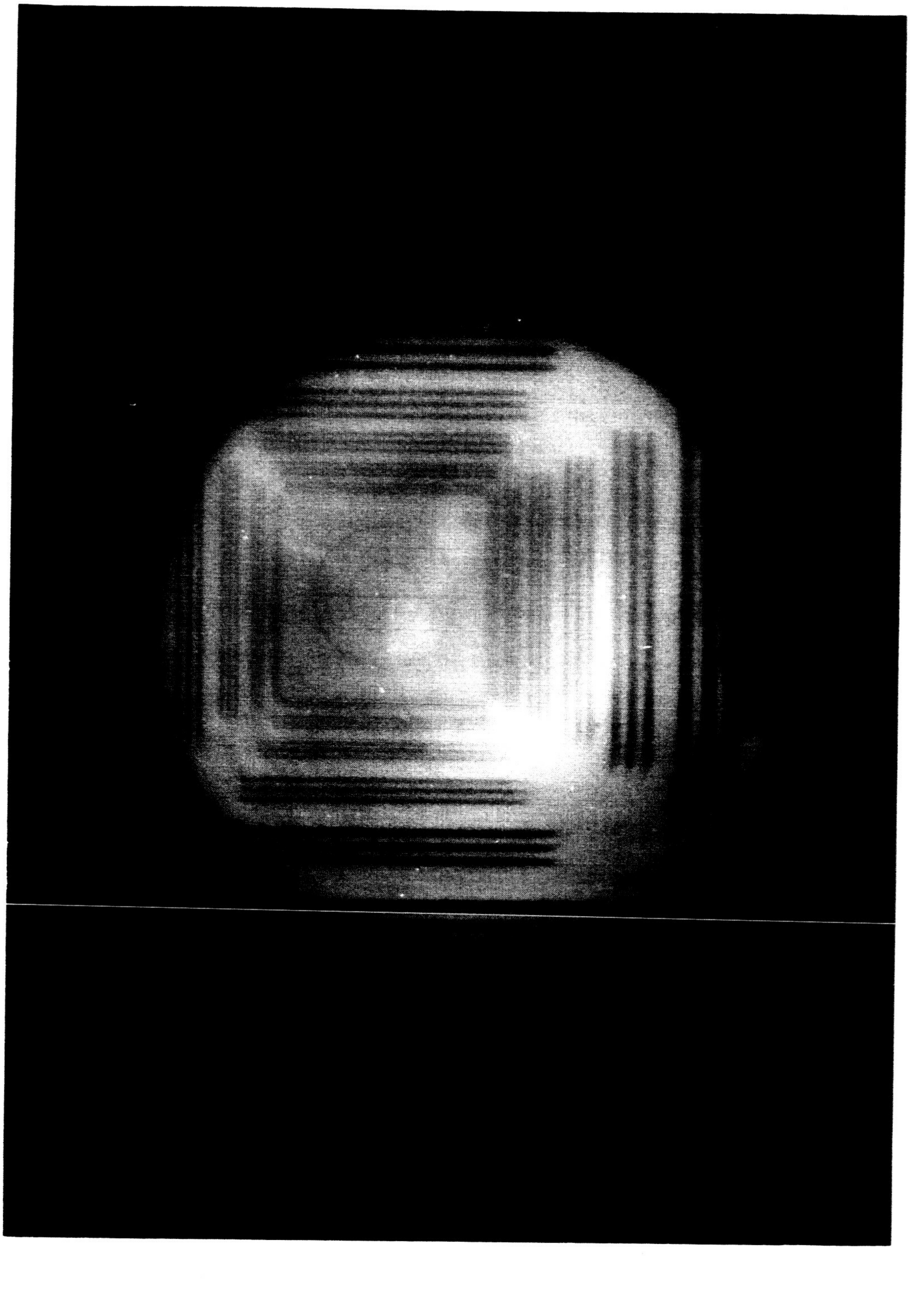

Figure 2

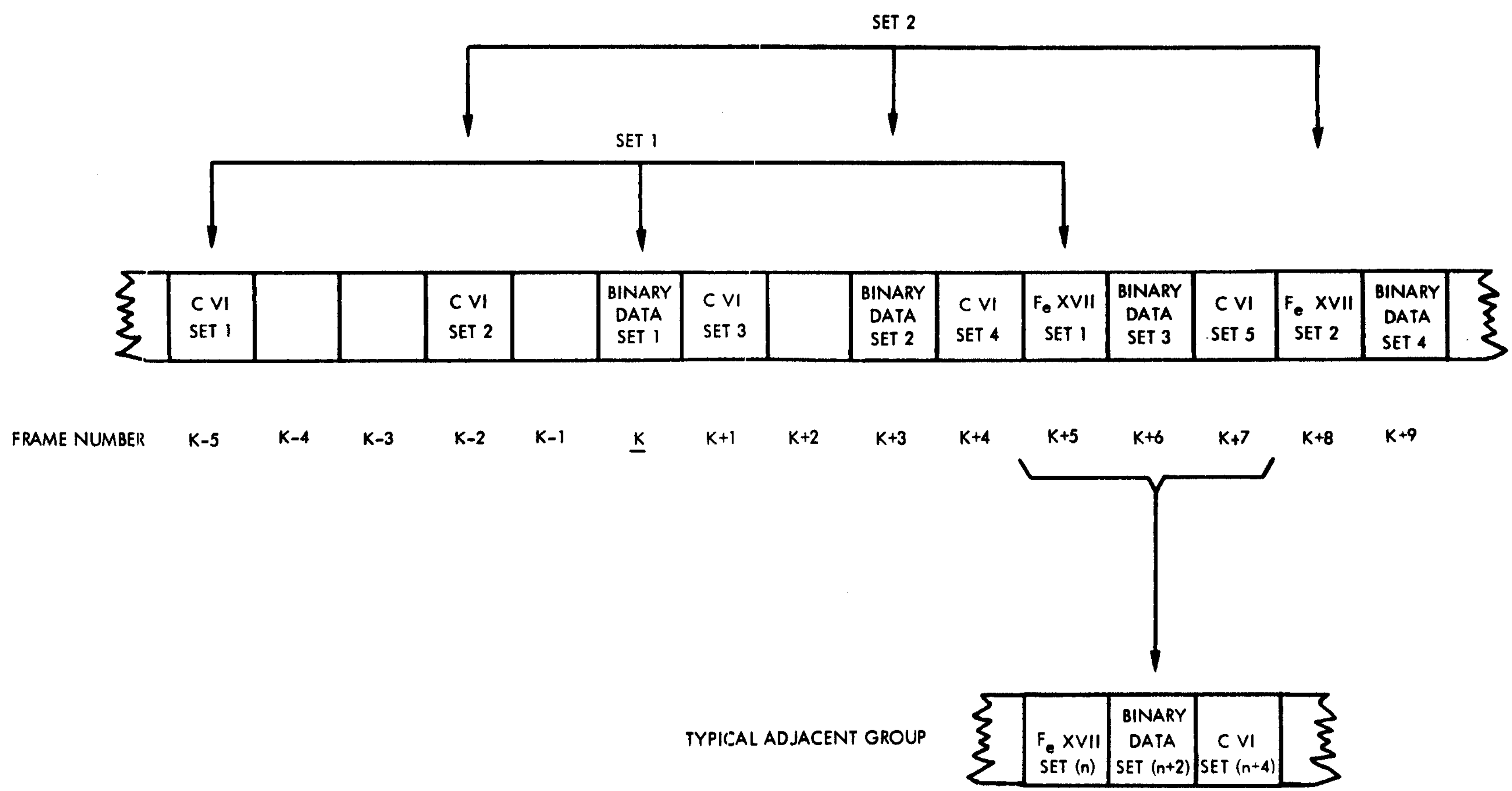
SET 2
SET 1
C VI SET 1
C VI SET 2
BINARY DATA SET 1
C VI SET 3
BINARY DATA SET 2
C VI SET 4
Fe XVII SET 1
BINARY DATA SET 3
C VI SET 5
Fe XVII SET 2
BINARY DATA SET 4
FRAME NUMBER
K-5
K-4
K-3
K-2
K-1
K
K+1
K+2
K+3
K+4
K+5
K+6
K+7
K+8
K+9
TYPICAL ADJACENT GROUP
Fe XVII SET (n)
BINARY DATA SET (n+2)
C VI SET (n+4)

Figure 3